

# Great Lakes Weekly Ice Cover Statistics

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## ABSTRACT

Data and methods used to calculate weekly ice cover statistics for a 30-winter (1973-2002) base period are documented. Spatial distribution patterns of the maximum, minimum, first quartile, median, and third quartile ice cover statistics are presented and discussed within the context of lake bathymetry ranges. Mild and severe winters are identified for each Great Lake. These data are available free of charge on CD-ROM, DVD, and are also on the Internet at: [http://www.glerl.noaa.gov/data/ice/atlas/weekly\\_stats/weeklystats.html](http://www.glerl.noaa.gov/data/ice/atlas/weekly_stats/weeklystats.html). Anomaly ice charts and other data given here for the first time are available in this report.

## INTRODUCTION

This report is part of a series of reports (Assel 2003a; Assel and Norton 2001; Assel et al. 2002; Assel et al. 2003; Assel 2003b; Assel 2004) documenting and supplementing data and products published as a NOAA Great Lakes Ice Atlas (Assel 2003c, available free of charge on CD-ROM or DVD and for browsing on the Internet at: <http://www.glerl.noaa.gov/data/ice/atlas/>). Here, data and methods used to calculate weekly ice cover statistics for a 30 winter (1973-2002) base period are described and discussed. ASCII files, graphics, and computer animations of ice cover statistics are available in Assel 2003c. Most place names cited in the text are shown in Figure 1.

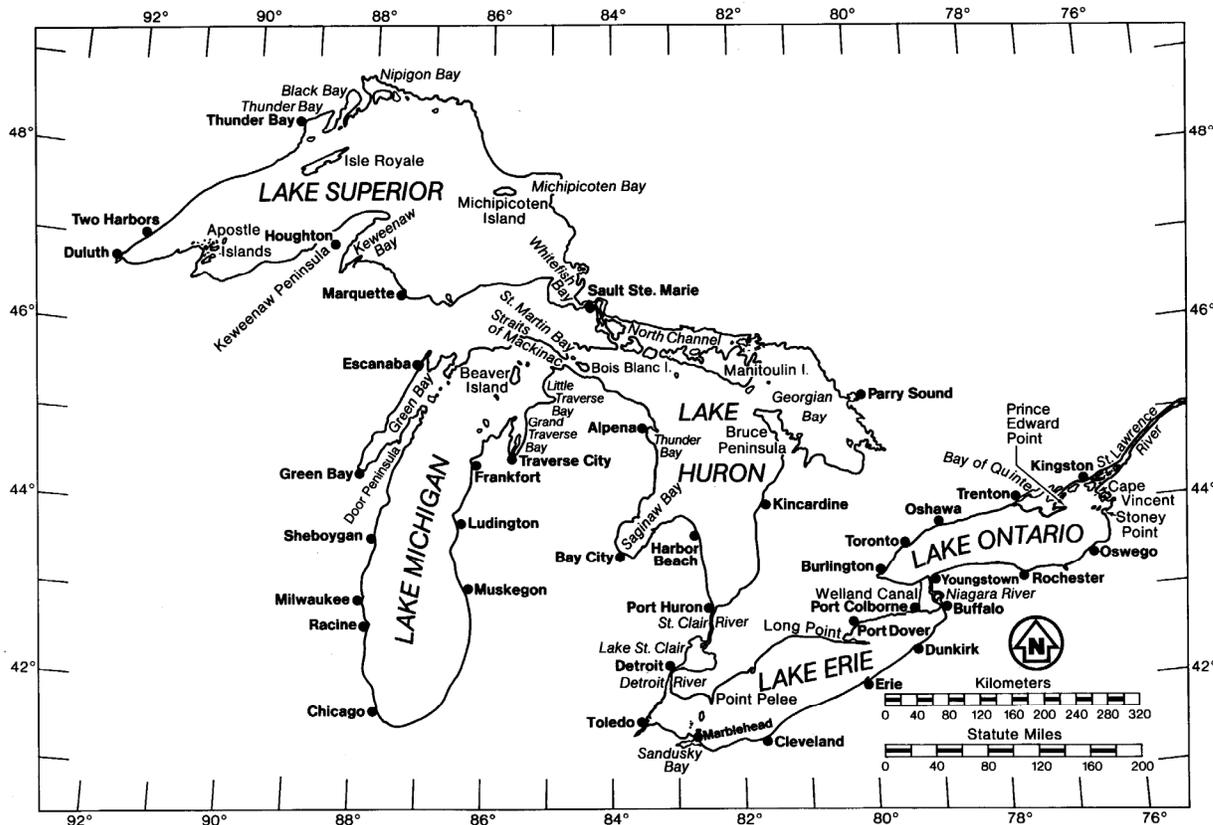


Figure 1. Place Names.

## DATA USED TO CALCULATE WEEKLY STATISTICS

The input data, Assel et al. (2002), consists of 1210 ASCII files of ice concentration. Each file consists of a grid of 510 rows by 516 columns with 38,193 over-water “grid cells” embedded in this matrix. Each over-water grid cell is coded with a number between 0 and 100, representing the percentage of that cell that is covered by ice. The latitude and longitude coordinate of the center of each grid cell is given in two fixed formatted text files, Latgrid.zip and Longrid.zip at: [http://www.glerl.noaa.gov/data/ice/atlas/daily\\_ice\\_cover/daily\\_grids/dailygrids.html](http://www.glerl.noaa.gov/data/ice/atlas/daily_ice_cover/daily_grids/dailygrids.html). Each grid cell has a nominal spatial resolution of 2.55 km x 2.55 km; the actual size of each grid cell varies with latitude. The temporal distribution of the data by winter season shows that there is a bias for a greater number of observations for the winters after 1989 (Fig. 2). This is because National Ice Center ice charts were digitized after 1989. Prior to winter 1989 only Canadian Ice Service ice charts were available. Thus, there is a potential bias in the calculation of weekly statistics that is addressed in the next section of this report.

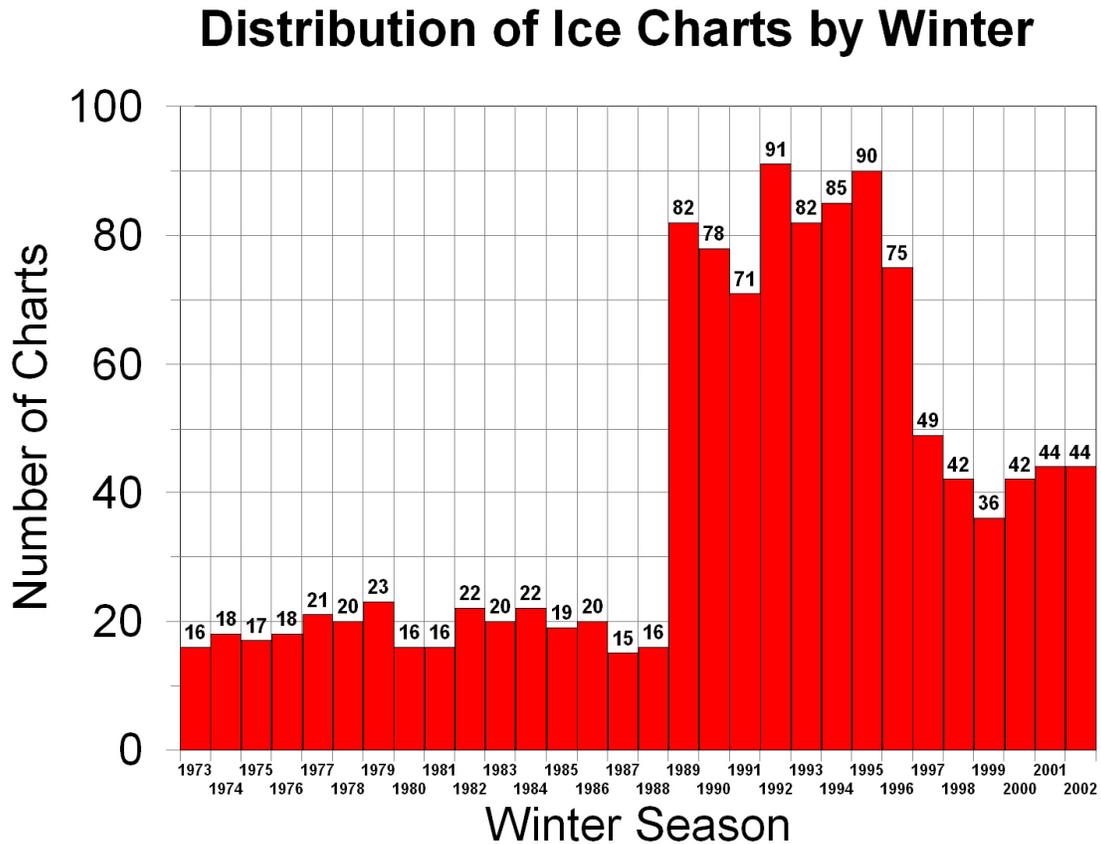


Figure 2. Ice charts digitized each of the 30-winter seasons: 1973 – 2002.

## METHODS

The data was partitioned into 173 overlapping weekly periods. Week 1 is December 1-7, week 2 is December 2-8, and so on to week 173, which is May 22-28, (Fig. 3). Thus, for any day in the winter season there is a weekly grid representative of that 7-day period. The number of winters with ice charts for each weekly period varied over the winter season. The statistics, described below, are most robust between the weeks with beginning dates from December 27 to April 17 because 90% to 100% of the 30 winters had observations for each 7-day period between those dates.

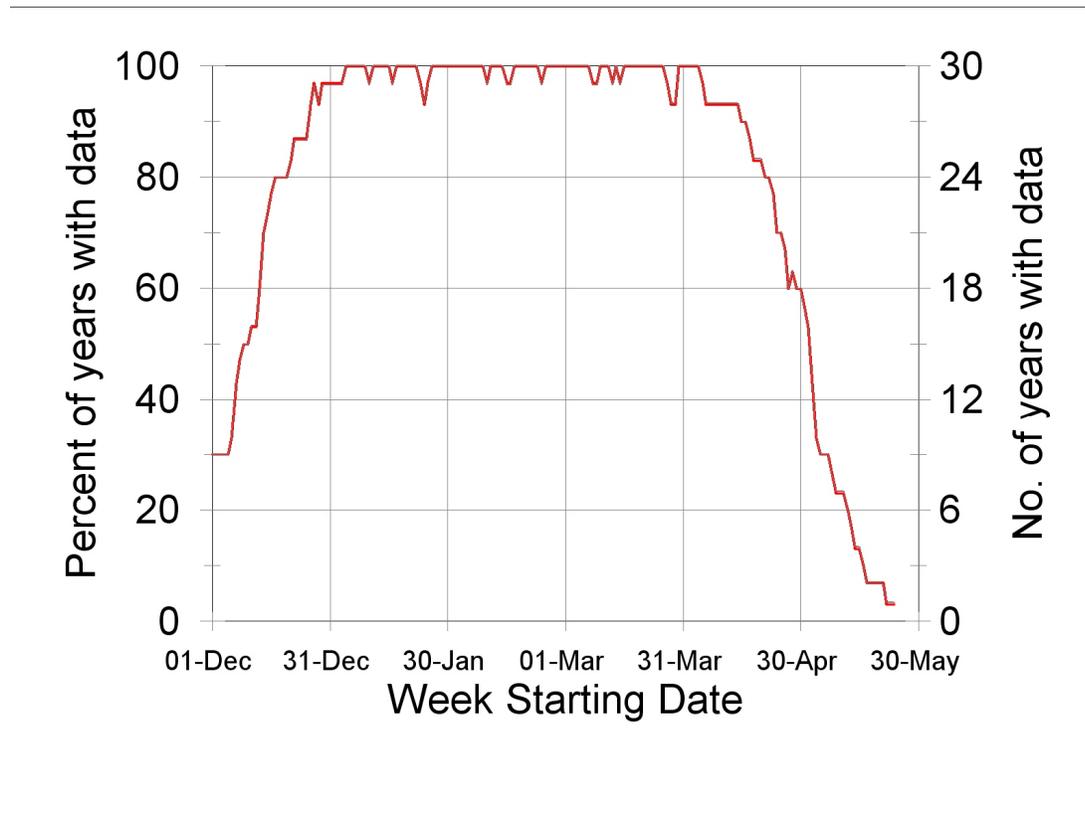


Figure 3. Number of winters with data for each weekly period.

Maximum and minimum values of ice concentration were found for each over-water grid cell for each weekly period using all the data for that week. Once this was done, the aggregated data for a given week was searched for the number of grids for each winter. If there was more than one grid for a given winter, a median grid was calculated and used to represent that winter for that weekly period. In this way no single winter (Fig. 2) would have greater influence than any other winter in computing the statistics (first quartile, median, third quartile, and standard deviation) of ice concentration for each grid cell for a give week. For example, 42 ice chart grids spanning 21 individual winter seasons were used for the week of December 15 - 21 (Table 1). These charts are in Assel (2003c). In years where there was more than one ice chart, a median grid was calculated. The Decembers in which this was done for the week of December 15-21 include: 1988 (3 charts), 1989 (4 charts), 1991 (4 charts), 1992 (4 charts), 1993 (3 charts), 1994 (4

charts), 1996 (2 charts), 1997 (2 charts), 1998 (2 charts), 1999 (2 charts), and 2001 (2 charts). The Decembers that had only one ice chart for that week include: 1972, 1976, 1977, 1978, 1981, 1982, 1983, 1985, 1995, and 2000.

Table 1 Distribution of Ice Chart Grids for December 15 – 21.

Grid No.	Year	Month	Day	Grid No.	Year	Month	Day
1	1972	12	20	20	1992	12	16
				21	1992	12	18
2	1976	12	16	22	1992	12	20
				23	1992	12	21
3	1977	12	21				
				24	1993	12	15
4	1978	12	18	25	1993	12	17
				26	1993	12	20
5	1981	12	21				
				27	1994	12	16
6	1982	12	21	28	1994	12	19
				29	1994	12	19
7	1983	12	20	30	1994	12	21
8	1985	12	21	31	1995	12	18
9	1988	12	16	32	1996	12	17
10	1988	12	19	33	1996	12	20
11	1988	12	21				
				34	1997	12	16
12	1989	12	15	35	1997	12	19
13	1989	12	17				
14	1989	12	18	36	1998	12	15
15	1989	12	20	37	1998	12	18
16	1991	12	15	38	1999	12	17
17	1991	12	16	39	1999	12	21
18	1991	12	18				
19	1991	12	20	40	2000	12	21
				41	2001	12	17
				42	2001	12	20

**Median and First and Third Quartiles.** The first quartile is defined as the 25% point in the cumulative frequency distribution (cfd), the median is the 50% point in the cfd, and the third quartile is the 75% point in the cfd. The difference between the maximum and minimum defines the range of ice cover under the current climate. The median, with half the observations below and half above, defines the typical value of ice cover each week for the 30 winters. The first quartile demarcates the boundary between the typical value and below-typical ice cover, and the third quartiles demarcates the boundary between the typical value and above-typical ice cover for the 30-winter base period. The standard deviation also provides a measure of the variation of ice cover (about the mean). The mean was not used in this analysis as the typical value because an earlier study indicated that ice cover frequency distributions are skewed (Assel et al., 2003), so the median is more representative of usually observed ice cover.

**Synoptic Median.** A synoptic median was also calculated for each lake. The synoptic median is defined as the original ice chart in the 7-day base period under consideration for which the sum of squares of the differences (observed minus median) for all grid cells for a given lake was smallest for all ice charts during a given weekly period. Thus, the "synoptic median" is the observed ice chart for a given lake that comes closest to the statistical median ice chart. The synoptic ice chart may be of more use to numerical models in which real world data, rather than statistics, are desirable. Note that for a given week, the synoptic median may occur on a different date for each Great Lake. The synoptic median for each lake could be combined to produce an "all lakes regional synoptic median" for a given week since all occur for the same weekly period.

## RESULTS

One ASCII grid was produced for each week for each statistic (maximum, minimum, median, first quartile, third quartile, standard deviation, and synoptic median) making a total of 1211 grids (7 statistics x 173 weekly periods). These grids have the same format and ice concentration codes described earlier under the "Data" section of this report. Ice concentration for a given statistic for a given week was plotted to portray spatial patterns. The spatial patterns for January 15, February 1, March 1, and April 1 are shown in Fig. 4 to illustrate the seasonal progression of the typical ice cover (represented by the median and synoptic median, Fig. 4a), the variation in the typical ice cover for each of the above dates in the winter season over the 30 winters (represented by the first and third quartiles, Fig. 4b), and the composite extremes (represented by the maximum and minimum, Fig. 4c) over the 30-winter base period. Ice concentration in Fig. 4 is color coded in 10% increments from 0%-10% (dark blue) to 90%-100% (red). The ASCII grids, the graphic plot files, and the computer animations for all 173 days of each of the seven statistics are not shown here for the sake of brevity but as shown below by the example for the median statistic all of these statistics are available on the Internet under the general link [http://www.glerl.noaa.gov/data/ice/atlas/weekly\\_stats/weeklystats.html](http://www.glerl.noaa.gov/data/ice/atlas/weekly_stats/weeklystats.html).

If you click on the link given above you will find the following text for links to the median statistic on that Internet page.

**Median** (the 50% point in the frequency distribution)

Computer Animation: [AVI format](#) | [FLC format](#)

ASCII Grid Files: [medgrid30.zip](#)

Graphic Files: [medplotpng30.zip](#)

Preview Selected [Graphic Files](#) at Weekly Intervals

By clicking on the appropriate icon shown in the above example for the median, you can download the selected data. The ASCII grids and graphic files are compressed, medgrid30.zip and medplotpng30.zip, respectively. Once you have downloaded these files to your computer, you need to un-zip them to access the 173 weekly files. The computer animation can be downloaded in a similar manner. You can also preview selected graphic files by placing your cursor over the "Graphic Files" icon on the "Preview Selected" line. *The individual ice charts in Figure 4 were obtained from the median, first quartile, third quartile, maximum, and minimum graphic files. The individual ice charts were reduced in size to produce Figure 4.*

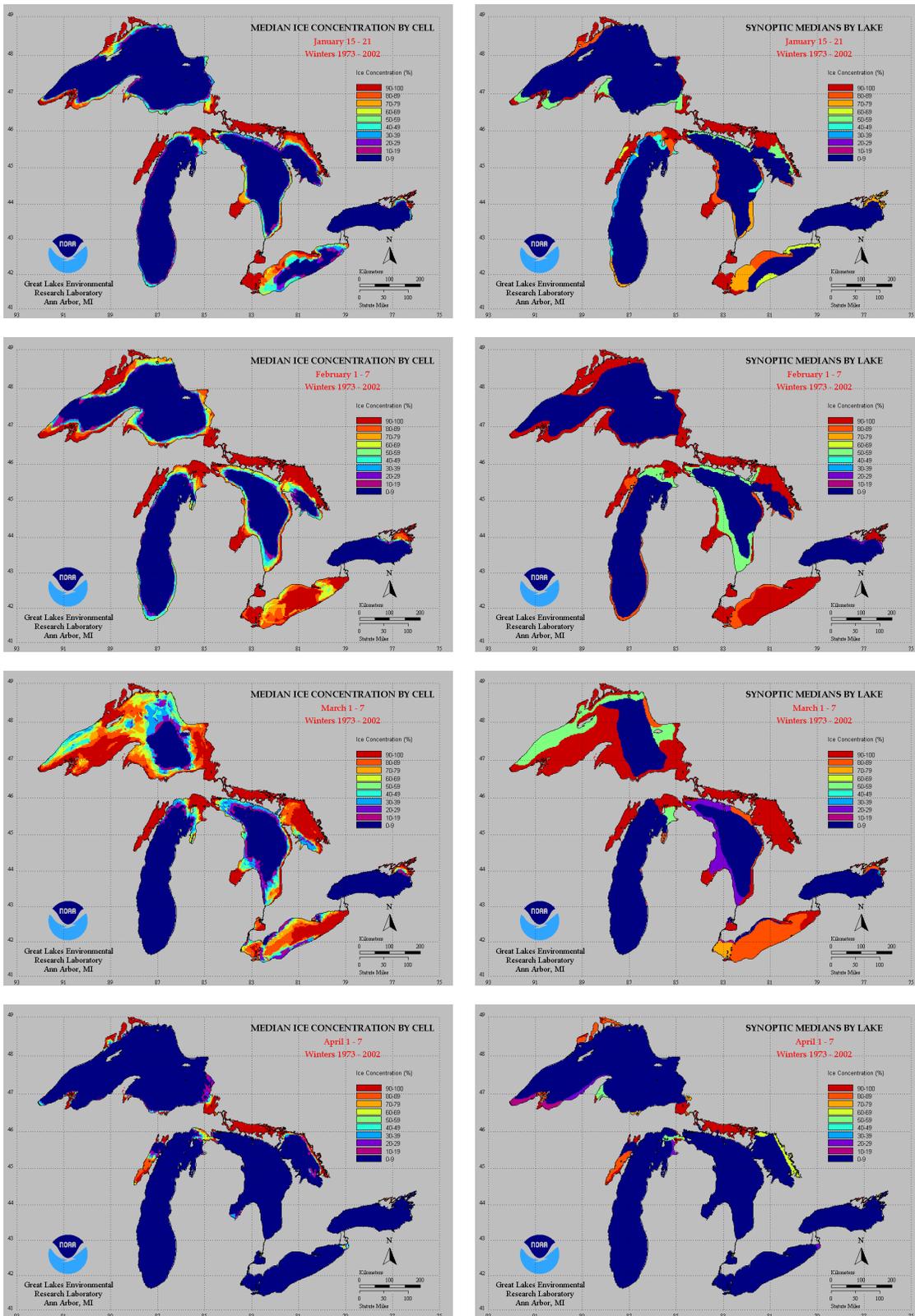


Figure 4a. Median (left) and synoptic median (right) ice covers for January 15, February 1, March 1, and April 1.

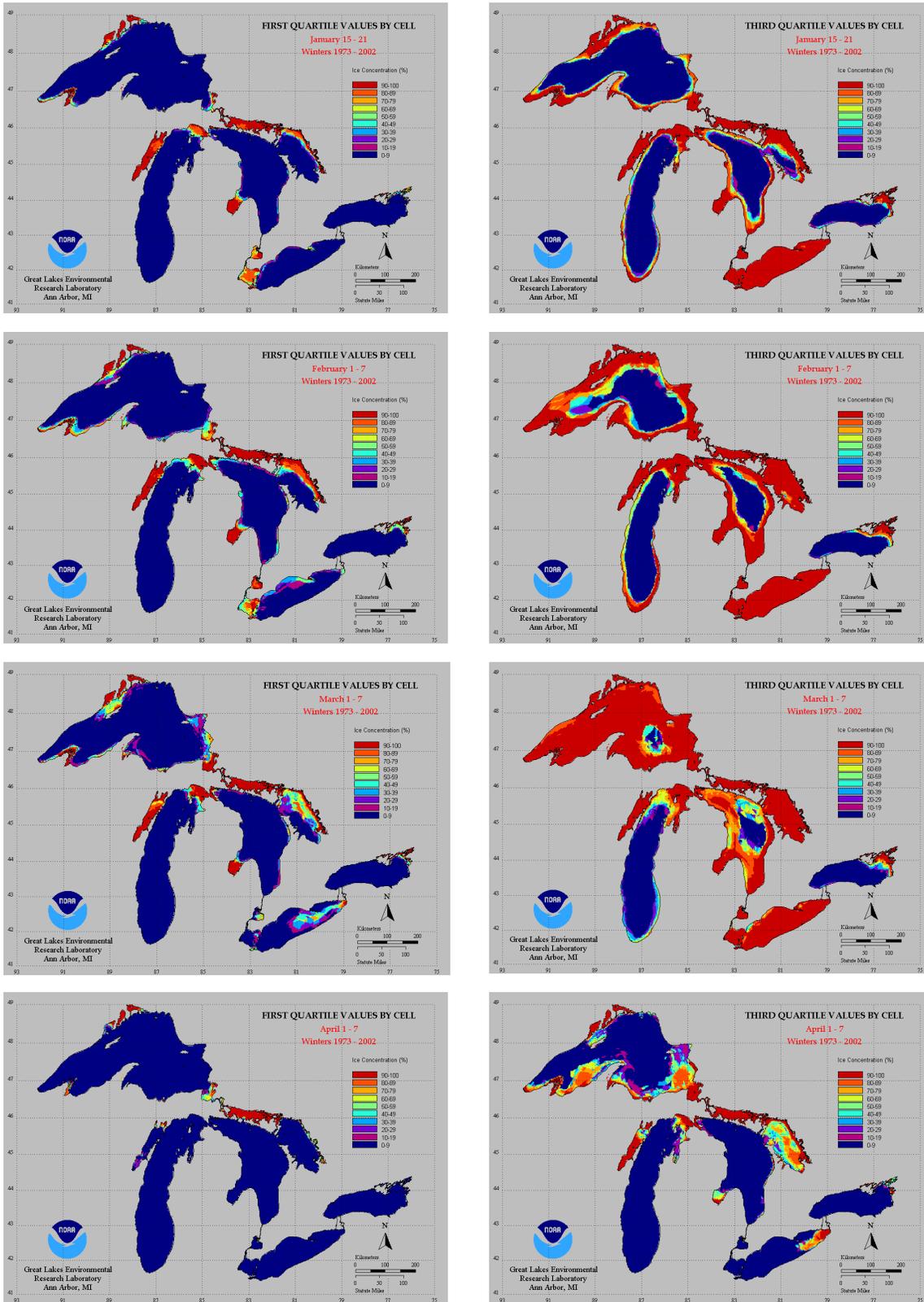


Figure 4b. First (left) and third (right) quartiles of ice cover for January 15, February 1, March 1, and April 1.

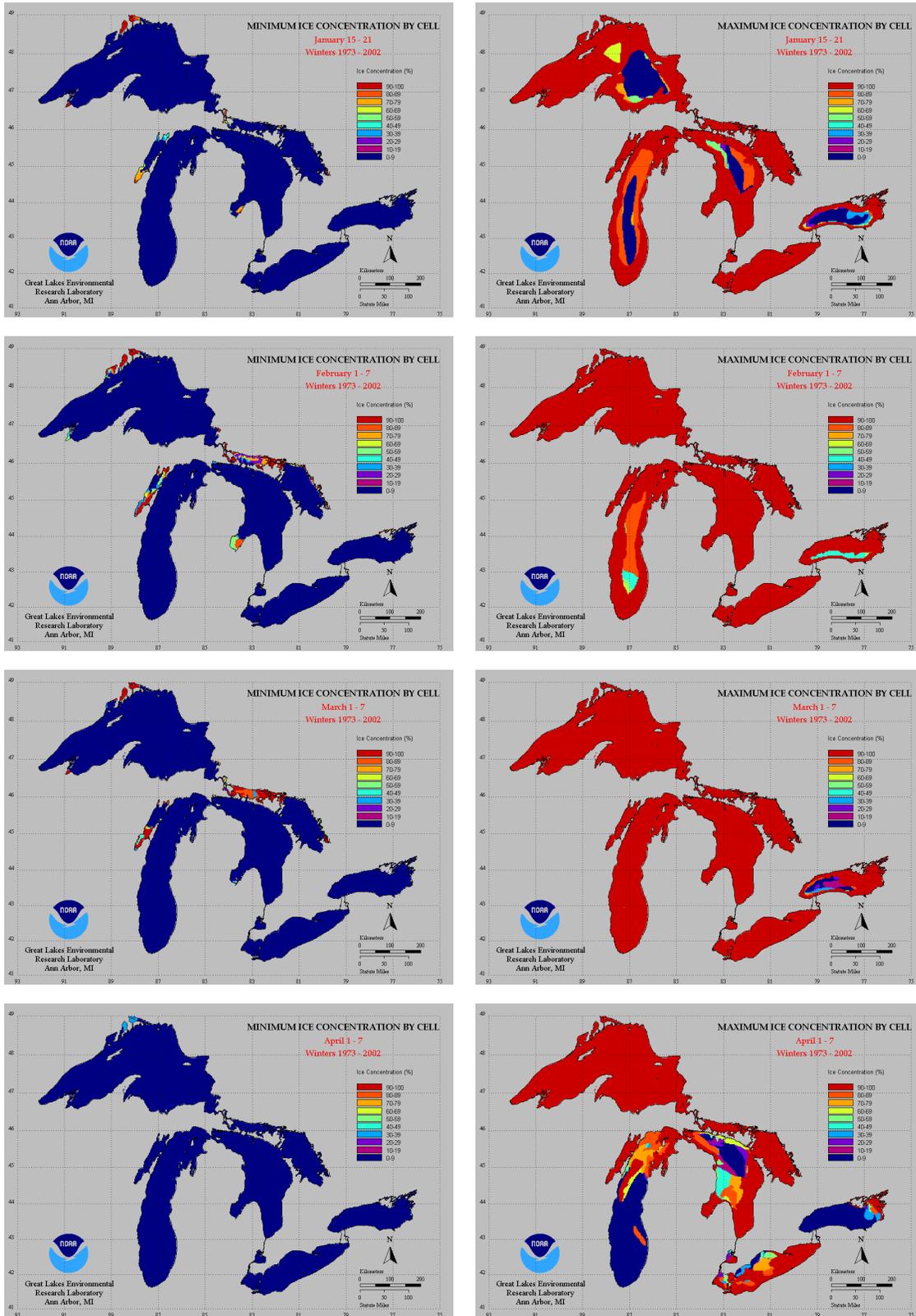


Figure 4c. Composite minimum and maximum ice cover for January 15, February 1, March 1, and April 1.

## ANOMALY ICE CHARTS

Daily anomaly ice charts were calculated by subtracting the 30-winter weekly median (for the mid-week day) from the same day for each of the 30 winter seasons, e.g. the March 1-7 median would be subtracted from the March 4 ice chart for each winter. *Anomaly charts provide a way to compare ice cover for any date of a given winter season with the long-term median.* Anomaly graphs and ASCII Grids are given as Appendix 1. *These data are not in Assel (2003c) and are made available here for the first time.* Spatial anomaly patterns for a mild (Assel et al. 2000), and a severe winter (Assel et al. 1996) are vividly portrayed in Fig. 5.

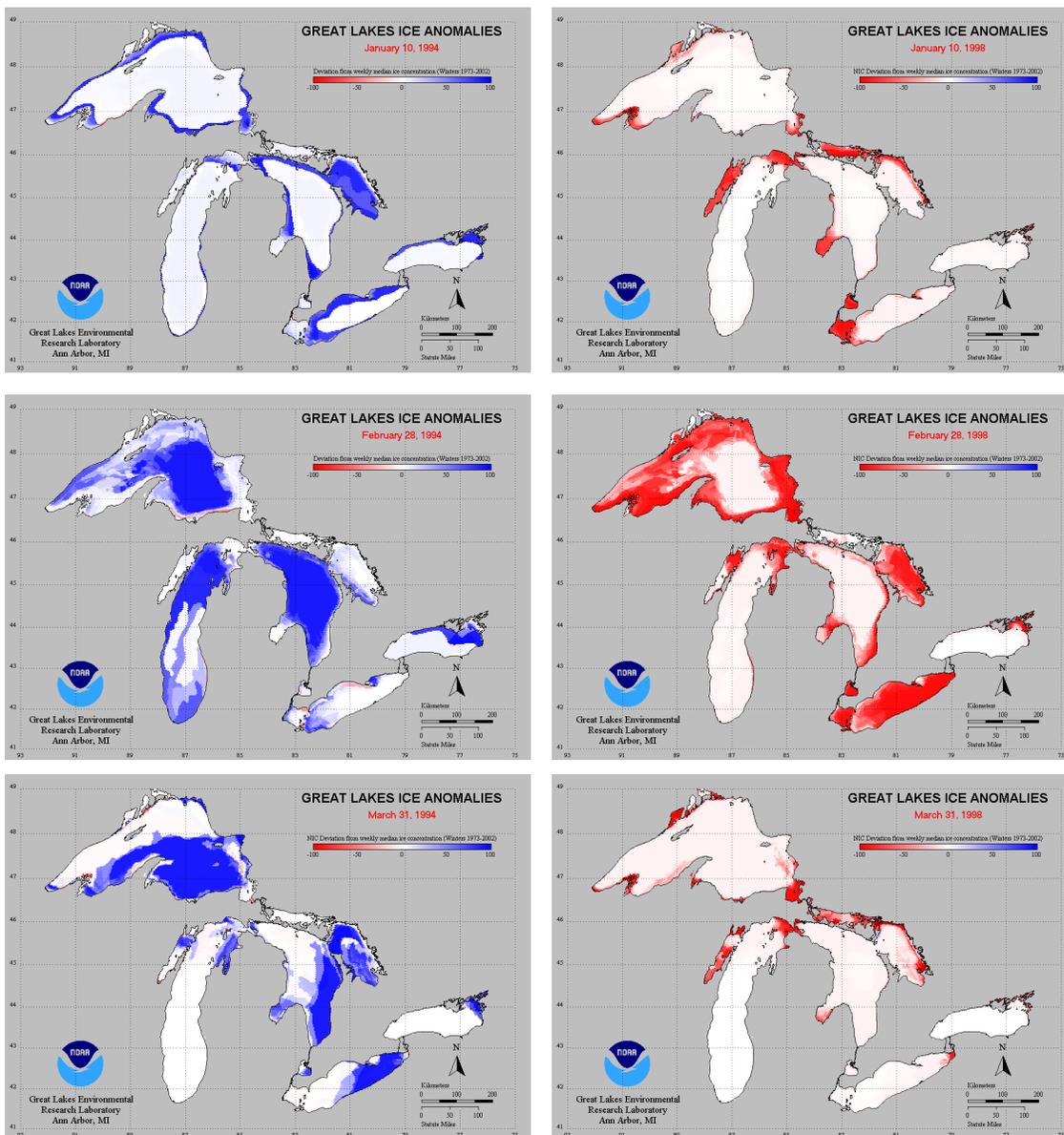


Figure 5. Ice cover anomaly: January 10, February 28, and March 31, 1994 (blue, above median), 1998 (red, below median).

## ICE COVER FOR SPECIFIC BATHYMETRY RANGES

Average ice cover for five discrete lake depth ranges was calculated from the weekly median, first quartile, and third quartile statistics for each Great Lake. The depth ranges for Lakes Superior, Michigan, Huron, and Ontario are 1-20 m, 21-50 m, 51-100 m, 101-200 m, and over 200 m. The depth ranges for Lake Erie, which is the shallowest of the Great Lakes, are 1-10 m, 11-15 m, 16-20 m, 21-30 m, and over 30 m. *These data, which provide information of the variation of ice concentration for lake surface areas associated with each discrete depth range, are not in Assel (2003c).* A grid mask coded for each Great Lake and a second grid mask with water depths were used to make these calculations. ASCII files of the grids and the ice data are included as Appendix 2. The ice data in Figs. 7, 9, 11, 13, and 15 was smoothed using a 7-day moving average. *Most of the place names used in the discussion below can be found in Fig. 1.*

### LAKE ERIE ICE COVER AND BATHYMETRY

Lake Erie has a mean depth of 19 m. This lake is divided into a west basin, from Toledo to Pt. Pelee, a central basin from Pt. Pelee to Long Point, and an east basin from Long Pt. to Buffalo,

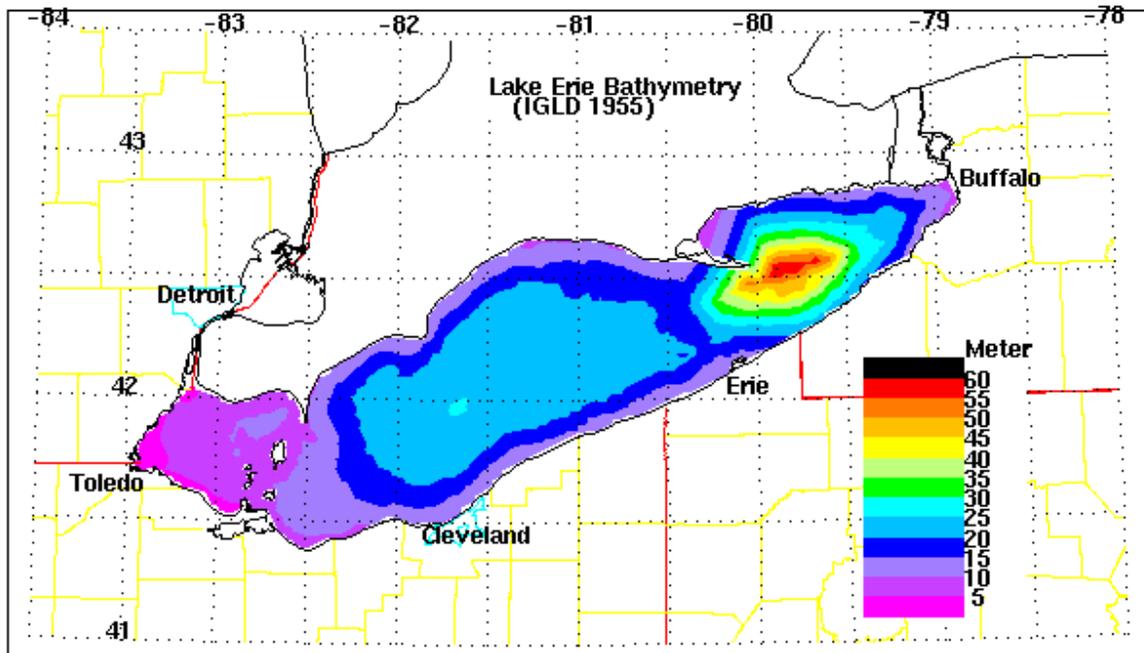


Figure 6. Lake Erie Bathymetry.

see Fig. 1 and Fig. 6. Depths of 1-10 m occur primarily in the west basin of the lake, depths of 11-15 m and 16-20 m occur primarily in the shore regions of the central and eastern basins of the lake, and depths of 21-30 m and depths of over 30 m occur primarily in the off shore waters of the central and eastern portions of the lake, with the deepest waters east of Point Pelee.

Note the general shape of the lake-averaged ice cover for each curve in Fig. 7a is mirrored in its depth decomposition in Figs 7b, 7c, and 7d. A major difference of the Q75 curve relative to Q50 and Q25 (Fig. 7a) is earlier ice formation, longer period near seasonal maximum ice extent (mid January to early March, when the lake is over 90% covered), and more extensive ice cover in

March and April. This pattern is also seen in Figs 4a-4b. For Q50, the period leading up to seasonal maximum ice starts late-December and culminates in mid-February with maximum ice cover at about 90%. The period of ice loss starts in the second half of February and is virtually complete by the end of March. For Q25, the period of ice formation starts the first half of January with a rapid increase in ice in February leading to an abbreviated maximum ice extent, about 60%, near mid February. The ice loss period runs from mid-February to mid-March. These patterns are also seen in Figs 4a-4b.

The spatial progression of ice cover is from the shallow west basin and lake perimeter, to the deeper areas of the central basin, to the deepest area of the lake located off of Long Point in the eastern lake basin. The depth decomposition of these patterns (Fig 7b, Fig 7c, and Fig 7d) reflect the general seasonal shift of ice cover from the shallow west basin where ice forms first to the deepest east lake basin where the ice lasts longest in the spring. This is shown by the greater ice concentrations in deeper depth ranges (16-20 m, 20-30 m, > 30 m relative to the 1-10 m and 11-15 m depth ranges) after the period of maximum ice extent. More information on Lake Erie ice cover is given in Assel (2004). The severe and mild Lake Erie ice cycles are given in Table 2. Lake-averaged maximum ice extent has varied from 5% to over 99%. Total observed ice cover variation is 10% or less to 90% or more from January 15 to March 1, Fig. 4c.

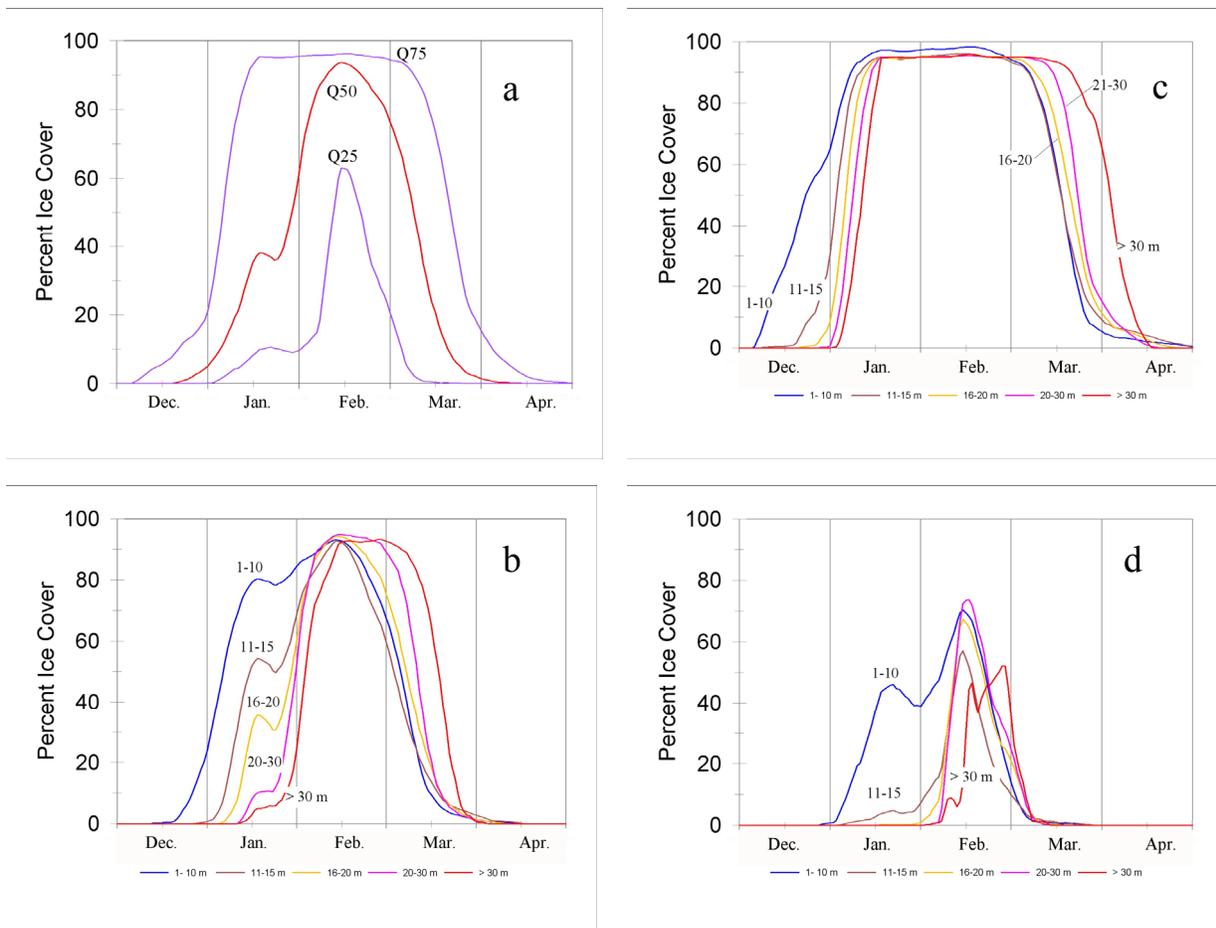


Figure 7. Average Lake Erie ice cover for a) the entire lake for first quartile (Q25), median (Q50), and the third quartile (Q75), and for discrete depth ranges for b) Q50, c) Q75, and d) Q25.

## LAKE SUPERIOR ICE COVER AND BATHYMETRY

Lake Superior, with a mean depth of 148 m, is the deepest of the Great Lakes. The 1-20 m, 21-50 m, and 51-100 m depth ranges occur most frequently along and extend out from the entire southern shore of the lake, in shoal areas associated with Isle Royale and a shoal area (Caribou Island) south of Michipicoten Island, and in the three large bays (Thunder, Black, and Nipigon Bays) along the north central lake shore (see Fig. 1, Fig. 8). These then are the shore and nearshore waters. The 101-200 m and > 200 m depth ranges are the offshore waters of Lake Superior. The deepest waters lay north and east of the Keweenaw Peninsula (Fig. 1), making the eastern basin of this lake the last to form ice because of its greater heat storage. There is also a deep trough off the northwest shore that, in conjunction with prevailing westerly winds, results in lower ice concentrations due to upwelling of warmer waters during the winter.

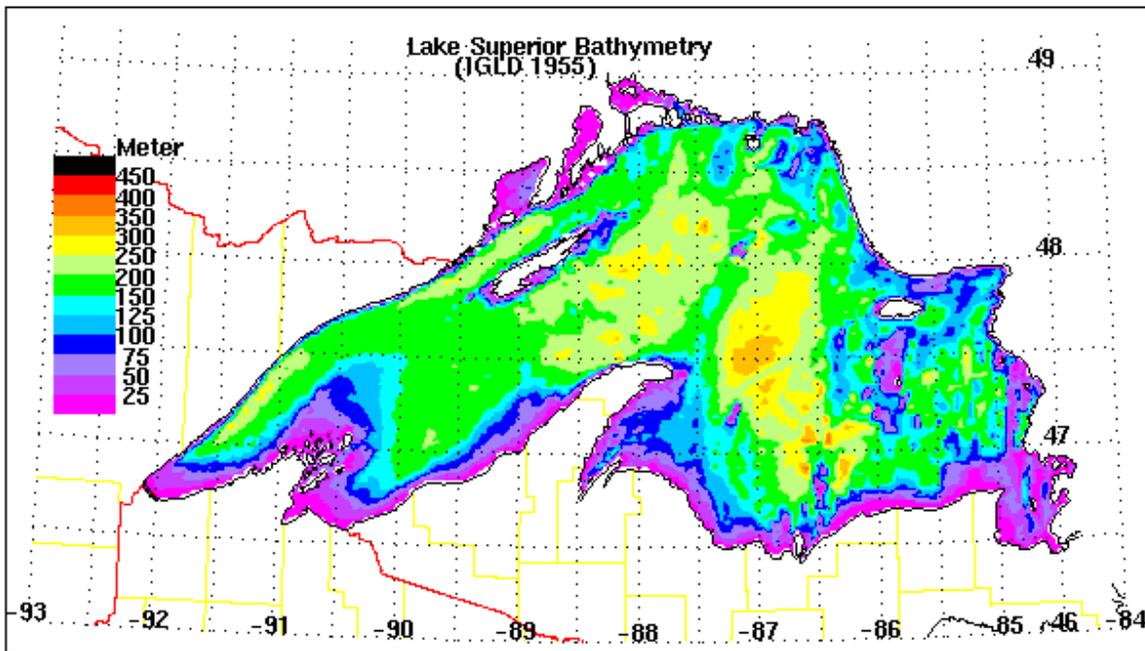


Figure 8. Lake Superior Bathymetry.

The annual lake-averaged ice cycle for Lake Superior (Fig. 9a) consists of a period of increasing shore ice extent in December and January leading to seasonal maximum ice extent (mid-February for Q25, first week in March for Q50 and Q75), followed by a period of decreasing ice extent, leading to a loss of all ice cover, mid-to-late March for Q25, late March to early April for Q50, and mid-to-late April for Q75.

The maximum lake-averaged ice cover for Q25 (Fig 9a, Fig. 4b) is less than 20% with (Fig. 9d), less than 80% for the 1-20 m range, 60% for the 21-50 m range, and 20% for the 51-100 m range, depths > 100 m have less than 5% ice cover. The maximum lake-averaged ice cover for Q75 (Fig. 9a, Fig 4b) is over 80% with (Fig. 9c) ice cover 80% or greater starting about mid January for the 1-20 m depths, late January for the 21-50 m depths, the first week of February for

the 51-100 m depths, the second half of February for 101-200 m depths and in early March for depths > 200 m. The period of maximum lake-averaged ice extent for Q50 (Fig. 9a, Fig 4a) is over 60% with (Fig. 9b) ice cover over 80% by the last week of January for 1-20 m depths, over 80% by mid February for 21-50 m depths, over 70% by the last week of February for 51-100 m depths, and over 50% in early March for 101-200 m depths. More detailed information on Lake Superior ice cover for mild, typical, and severe ice cycles is given in Assel (submitted, 2005b).

Lake Superior ice cycles classified as severe and mild are shown in Table 2. The severe ice cycles have ice cover similar to or greater than Q75 (Fig. 9c), and the mild ice cycles have ice cover similar to or less than Q25 (Fig. 9d). Lake-averaged maximum ice cover has varied from 11% to over 99%. The composite maximum and minimum ice charts (Fig. 4c) show that with the exception of portions of the east lake basin in January, ice cover on this lake varied from less than 10% to 90% over most grid cells from February 1 to April 1.

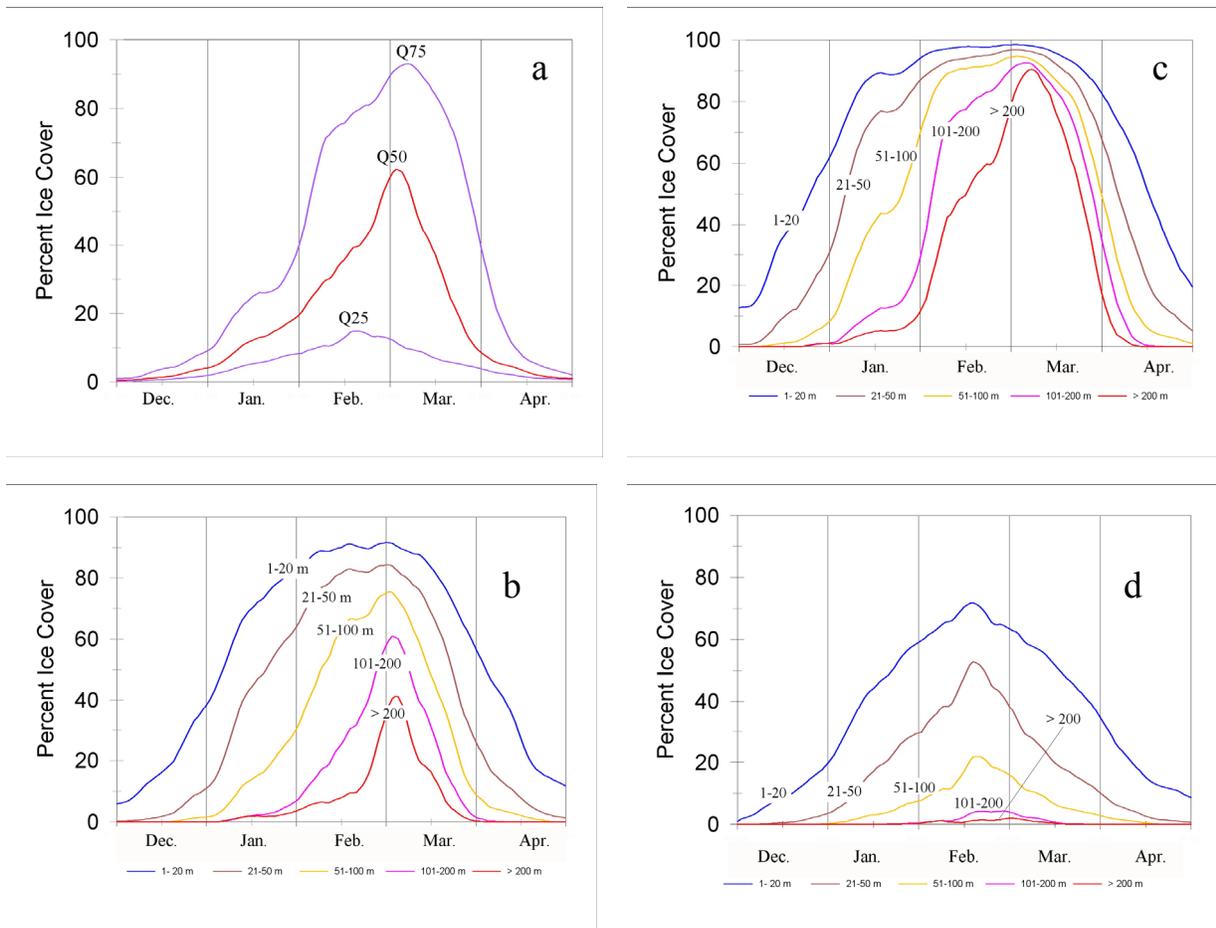


Figure 9. Average Lake Superior ice cover for a) the entire lake for the first quartile (Q25), median (Q50), and the third quartile (Q75), and for discrete depth ranges for b) Q50, c), Q75, and d) Q25.

## LAKE HURON ICE COVER AND BATHYMETRY

Lake Huron has a mean depth of 58 m, and is the second shallowest of the Great Lakes. Lake depths (Fig. 10) of 1-20 m and 21-50 m, include the entire perimeter of the lake, extend off shore, and include the Straits of Mackinac, Thunder Bay, Saginaw Bay, the southern basin of the lake, Georgian Bay, and the North Channel (Fig. 1). Depths of 51-100 m occur in deeper areas of Georgian Bay and south of a line from Kincardine, Ontario to Alpena, Michigan. The deepest mid lake area, depths of 101-200 m, occurs northeast of that line. That is the last area of the lake to form ice and the first to lose it.

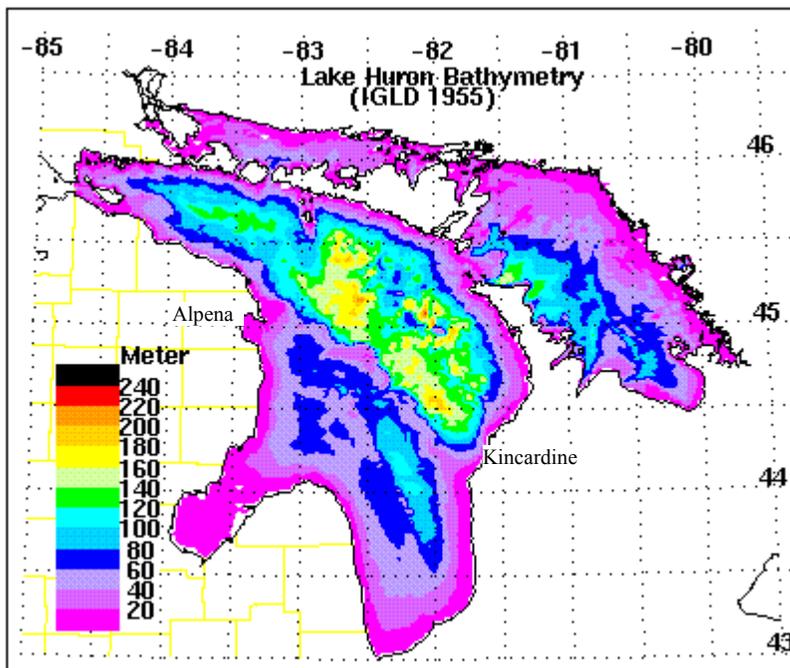


Figure 10. Lake Huron Bathymetry.

Ice first forms in the shallow areas of the perimeter of Lake Huron in December and January, reaches its maximum extent from mid-to-late February, decreases in extent in March, and by late March to mid-April covers less than 20% of the lakes surface (Fig. 11a, Fig. 4a). The largest increase in ice extent occurs in January, and the largest decrease occurs in March. The seasonal maximum lake-averaged ice extent can vary from approximately 80% (Q75) to 30% (Q25), Fig. 11a, Fig 4b. The maximum ice cover in the shore zone (1-20 m depth range) varies from an average of over 90% for Q75 (Fig. 11c), to over 65% for Q25 (Fig. 11d), and is over 80% for Q50 (Fig. 11b). Shore areas include Saginaw Bay, shallow areas of Thunder Bay, North Channel, and Georgian Bay, and much of the rest of the lake's perimeter. The duration of maximum ice extent for the 1-20 m depths is approximately mid-January to mid-March for Q75 and Q50 and less than a week around mid-February for Q25. Mid lake depths (51-100 m) have maximum ice extent that ranges from an average of over 70% for Q75 (Fig. 11c) to between 5-10% for Q25 (Fig. 11d), and is over 30% for Q50 (Fig. 11b). These mid-lake depths cover most of the southern and western portion of the lake (Fig. 10) and portions of Georgian Bay, North Channel. The duration of maximum ice in these mid-lake areas is approximately mid-February

to early to mid March. The deepest area of the lake (101-200 m depths) is located in the north and east mid-lake area (Fig. 10). The maximum ice cover for the 101-200 m depths occurs the second half of February to early March and varies from an average between 45%-50% for Q75 (Fig. 11c) to less than 5% for Q25 (Fig. 11d), and less than 15% for Q50 (Fig. 11b). The severe and mild Lake Huron ice cycles are identified in Table 2. Lake-averaged maximum ice cover has varied from 29% to 98%. The total variation in seasonal ice cover for any grid cell on Lake Huron is portrayed in Fig. 4c, which shows that ice concentration has varied from 10% or less to 90% or more over most of the lakes surface from mid January until the end of March.

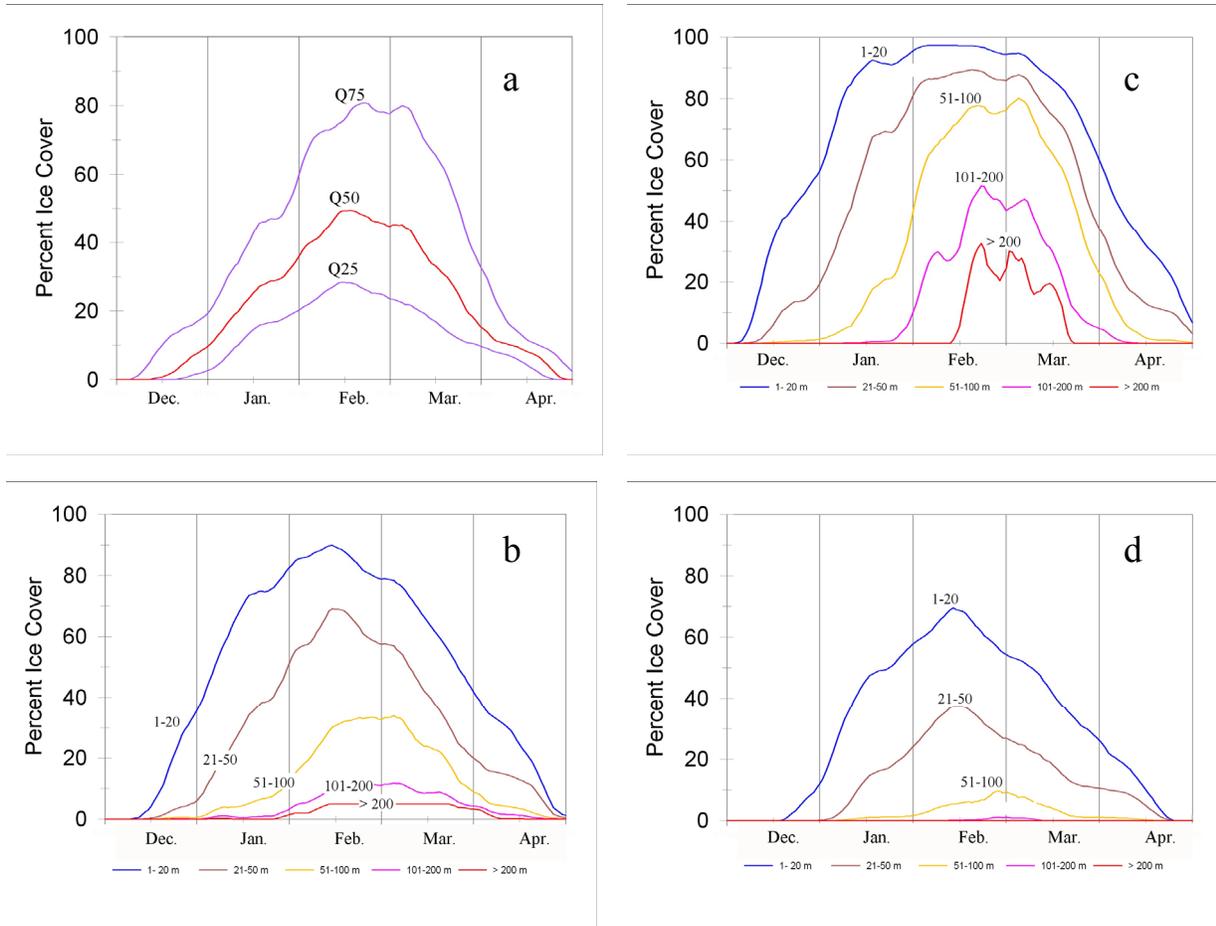


Figure 11. Average Lake Huron ice cover for a) the entire lake for the first quartile (Q25), median (Q50), and third quartile (Q75), and for discrete depth ranges for b) Q50, c) Q75, and d) Q25.

## LAKE MICHIGAN ICE COVER AND BATHYMETRY

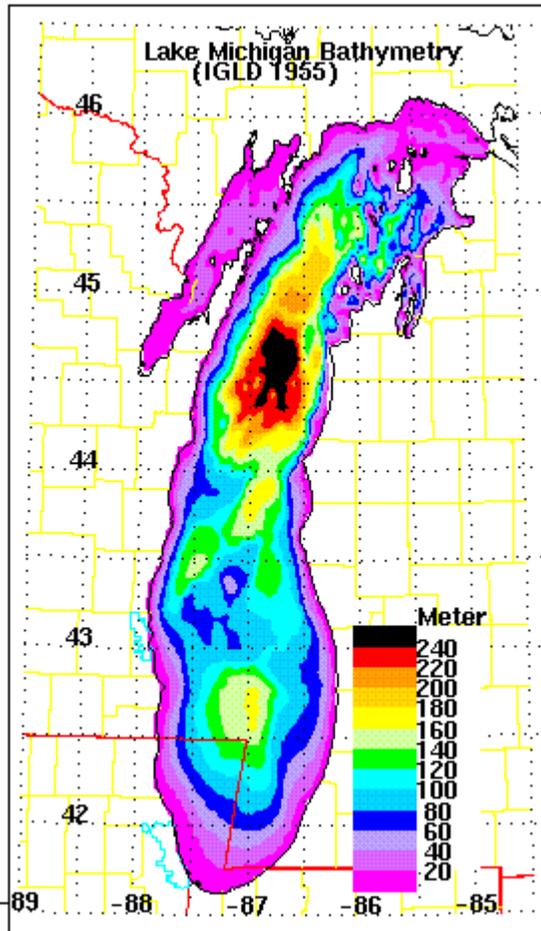


Figure 12. Lake Michigan Bathymetry.

Lake Michigan has a mean depth of 85 m. The shore areas (Fig. 1, Fig. 12), i.e., depths of 1-20 m and 21-50 m, line the lake's perimeter and include Green Bay and the lake from the Straits of Mackinac to Beaver Island and the Fox Islands in the north. The relatively narrow strip of 1-20 m and 21-50 m depths along the west and east shores becomes wider south of about 43° N. Depths of 51-100 m are more prevalent in mid lake area of the southern lake and depths of 101-200 m are more prevalent in mid-lake areas of the northern portion of Lake Michigan. However, because of its large north to south extent, air temperatures tend to be lower in the northern half of the lake. Maximum Lake Michigan ice cover (Fig. 13a) is much less than that of Lakes Erie, Superior, and Huron (Fig. 7a, Fig 9a, and Fig 11a) because Lake Michigan has more heat storage capacity (due to greater depth) relative to Lake Erie and less heat loss potential (due to milder air temperatures) relative to Lakes Huron and Superior. Maximum lake-averaged ice cover occurs near mid February (Fig. 13a) and varies from about 40% for Q75 to about 10-15% for Q25, and is about 20% for Q50. The average ice cover for 1-20 m depths is over 80% from about mid-January to the end of February for Q75 (Fig. 13c). The Q75 21-50 m and the 51-100 m depth ranges have average ice covers of over 60% and over 15%, respectively, for most of February.

At the other extreme (Q25, Fig. 13d) the 1-20 m depth range has ice cover over 40% from late January to early March, the 21-50 m depth range has ice cover over 20% in February and early March, and the average ice cover is virtually nil for depths over 50 m. For Q50, (Fig. 13b) the 1-20 m depths have ice that averages over 60% from late January to late February, the 21-50 m depths have ice that averages over 30% from late January to early March, and the 51-100 m depths have ice that averages over 5% for most of February. The ice cover in the northern portion of the lake is usually more extensive than in the southern portion due to lower air temperatures and the large shallow areas located there, (Fig. 4a-4b). Lake-averaged maximum ice cover in Lake Michigan has varied from 13% to over 96%, the years of extreme ice cycles are shown in Table 2. The composite maximum and minimum ice charts (Fig. 4c) show that ice cover can vary over most of the lake's surface from 10% or less to 90% or more during much of the winter.

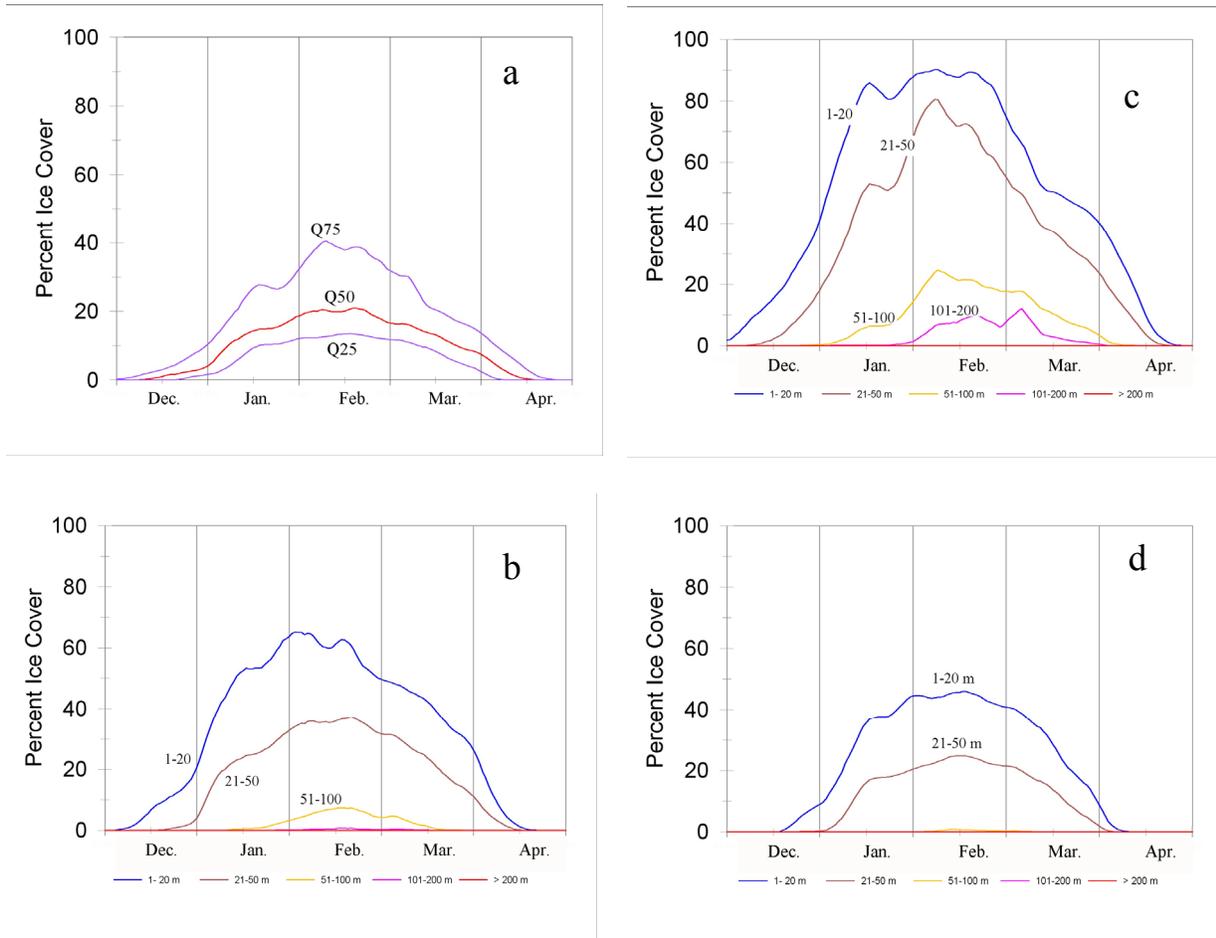


Figure 13. Average Lake Michigan ice cover for a) the entire lake for the first quartile (Q25), median (Q50), and third quartile (Q75), and for discrete depth ranges for b) Q50, c) Q75, and d) Q25.

## LAKE ONTARIO ICE COVER AND BATHYMETRY

The mean depth of Lake Ontario is 86 m. The 1-20 m and 21-50 m depths line the perimeter of the lake (Fig. 14), and include much of the northeast end of the lake from Stoney Point to Prince Edward Point (Fig. 1).

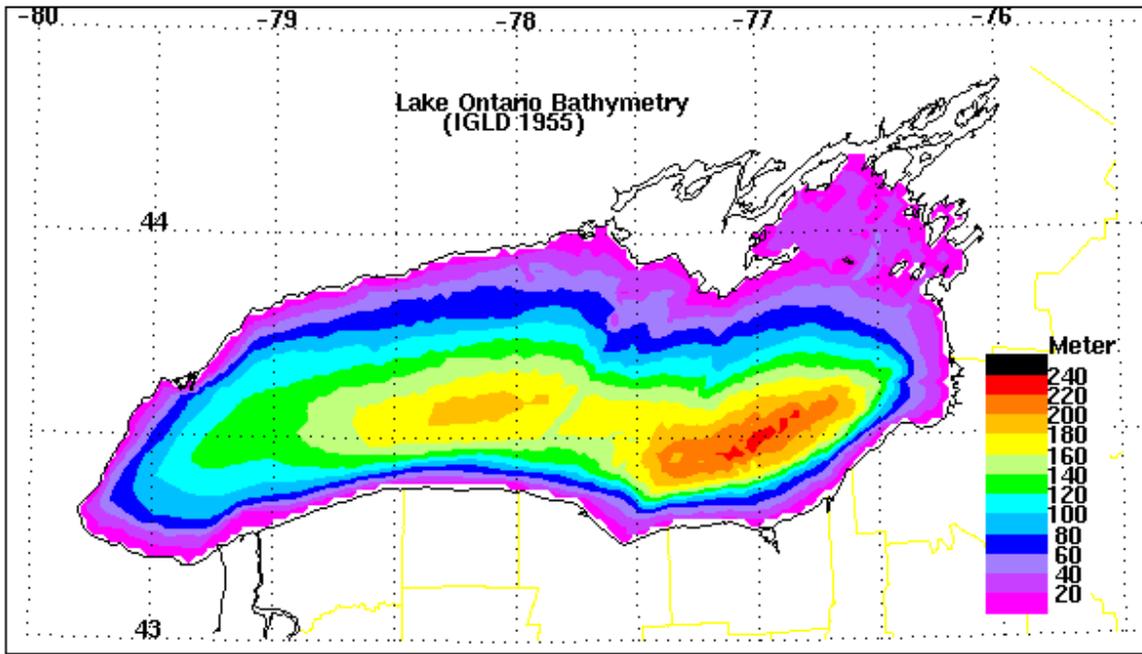


Figure 14. Lake Ontario Bathymetry.

Lake Ontario's typical (Q50) ice cover (Fig. 15a) is less than Lake Michigan's (Q50, Fig. 13a) and tends to be located in the northeast quadrant of the lake (Fig. 4a). Lake Ontario's mean depth is similar to that of Lake Michigan, giving it a substantial heat storage capacity. However, unlike Lake Michigan, Lake Ontario is located substantially south of  $45^{\circ}$  N, and so it is exposed to milder air temperatures than northern portions of Lakes Michigan and Huron and all of Lake Superior. For these reasons, maximum lake-averaged ice cover is lower on this lake than Lakes Erie, Superior, Huron, and Michigan. Maximum lake-averaged ice cover for Q75 (Fig. 15a) is less than 30%, for Q50 is less than 20%, and for Q25 is less than 10%. The ice cover is usually limited to the 1-20 m and 21-50 m depths where the average ice cover varies between 50-60% and 40-50% respectively for Q75 (Fig. 15c), between 40-50% and 20-30% respectively for Q50 (Fig. 15b), and between 30-40% and 10-15% respectively for Q25 (Fig. 15d), during the month of February. Only in Q75 (Fig. 15c) is there substantial depth-averaged ice cover for the 51-100 m depths, maximum value ranging from 10% to 15% in mid February. The ice cover is virtually gone by the end of March (Figs. 4a-4b) with the exception of some ice in the shore areas located in the northeast quadrant of the lake, e.g., the Bay of Quinte. Lake Ontario ice cycles classified as severe and mild are given in Table 2. Lake-averaged maximum ice extent has varied from 6% to 90%. The composite maximum ice cover charts (Fig. 4c) show that in a few extreme winters (e.g., 1979, 1994) extensive ice cover has formed in the deep mid-lake area of this lake.

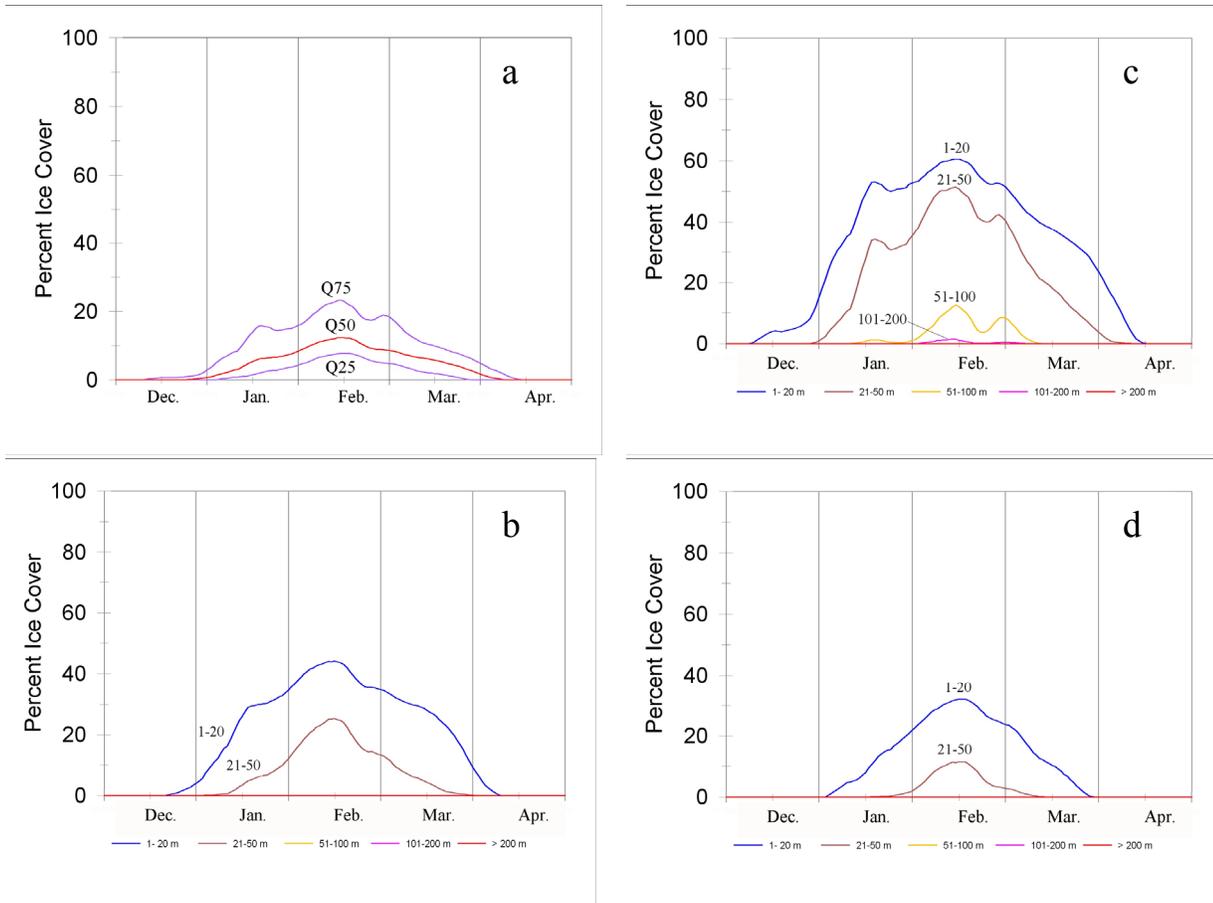


Figure 15. Average Lake Ontario ice cover for a) the entire lake for the first quartile (Q25), median (Q50), and the third quartile (Q75), and for discrete depth ranges for b) Q25, c) Q50, and d) Q75.

Table 2 Distribution of Severe and Mild Winters*												
	Severe**						Mild***					
Erie	1996	1986	1984	1982	1978	1977	2002	1998	1991	1987	1983	1985
Superior	1996	1994	1986	1979	1977	1974	2002	2000	1999	1998	1995	1987
Huron	1996	1994	1982	1979	1978	1977	2002	2000	1999	1998	1987	1983
Michigan	1994	1986	1982	1979	1978	1977	2002	2000	1998	1995	1987	1983
Ontario	1994	1986	1982	1979	1978	1977	2002	1999	1998	1987	1983	1975

\* Listed in order of severity given in Assel (submitted, 2005a).

\*\* Severe ice cycles occurred on all Great Lakes in 1977, on four Great Lakes in 1978, 1979, and 1994.

\*\*\* Mild ice cycles occurred on all Great Lakes in 1987, 1998 and 2002, on four Great Lakes in 1983.

## SUMMARY

Data and methods used to calculate the weekly ice cover statistics for a 30-winter base period (1973-2002) are described. The entire data set was not presented here for the sake of brevity, but it is available at [http://www.glerl.noaa.gov/data/ice/atlas/weekly\\_stats/weeklystats.html](http://www.glerl.noaa.gov/data/ice/atlas/weekly_stats/weeklystats.html). Anomaly ice charts, the differences from the median, not given in Assel (2003c) were presented. Anomaly ice charts, Appendix1, provide a method to quantify ice cycle severity for any given winter and area of the Great Lakes. An overview of the typical value (median ice charts), variation of the typical value (first and third quartile) and climatic extremes (composite maximum and minimum) of ice cover was presented in graphical form (Figs 4a-4c). The ice cover between the first and third quartile show that most areas of the Great Lakes range from less than 10% ice cover to 80% or more over much of the winter season during the 30-winter base period. This variation is used to define the typical range of ice cover, mild winters have ice cover below the first quartile, and severe winters have ice cover above the third quartile. The spatial-averaged ice cover for five discrete depth ranges was calculated for each Great Lake for the median, first quartile, and third quartile for each week (Appendix 2). Plots of these data portray the depth dependent seasonal progression of ice cover for typical, severe, and mild winters (Fig. 7, Fig. 9, Fig. 11, Fig. 13, and Fig. 15) for Lakes Erie, Superior, Huron, Michigan, and Ontario, respectively. All of these data provide a baseline of Great Lakes ice cover over the last three decades of the 20<sup>th</sup> century and first years of the 21<sup>st</sup> century.

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## APPENDIX 1. DAILY ANOMALY DATA

Introduction. Ice cover anomalies grids are the difference between the weekly median ice concentration grid and the ice concentration grid for the daily ice chart in a given year with the date (month and day) that corresponds to the center day (fourth day) of the weekly median. Differences were calculated for each over-water grid cell. The first weekly median ice chart is for December 1-7. The last median ice chart is for the week of May 22-28. Thus, anomaly ice chart can be calculated for all days between December 4 and May 25. The actual number of anomaly ice charts for a given winter depends upon the date of the first and the date of the last ice chart. It is not possible to calculate an ice anomaly chart prior to December 4 or prior to the date of the first observed ice chart if it is later than December 4, and after May 25, or after the date of the last observed ice chart if it is earlier than May 25. The daily ice charts used to calculate the median are described in Assel (2003c) under “Daily Ice Cover Time Series”.

Anomaly Ice Charts Grids. Anomaly ice chart grids are in compressed files. The file name encodes the winter and source of the anomaly charts (YYYY.zip and YYYYN.zip) where YYYY is the winter (1973-2002). There are Canadian Ice Service (CIS) files for winters from 1973 to 1995 and National Ice Center (NIC) files for winters from 1989 to 2002. The NIC anomaly ice file names for 1989 to 1995 have an “N” after the year. Ice charts after 1995 are a mix of CIS and NIC ice charts. The anomaly grid files contained in the compressed files have names that encode the date and type of data, i.e., interpolated data, or observed data.

Grid File Names: YYdddI.ANO and YYdddI.ANO

YY = winter season (for example, 73 for 1973, 74 for 1974, ...102 for 2002)

ddd = day of the winter season (101=Dec 1, ...132=Jan 1, ...273=May 22)

I = data indicator: I = 1 (interpolated data), I = 2 (observed data)

Grid File Format:

510 records, each record has 516 "grid cells" in integer (I3) format.

Ice and Land Grid Cell Codes: Land grid cells have a value of 999. Ice cover anomalies can vary from -99 to +99. Over water cells with missing data have a code of 888.

Anomaly Ice Chart Images and Animations. Daily Image files and computer animations of the daily image files of ice concentration anomalies over the Great Lakes for a given winter were produced from the daily anomaly ice chart grid files. Image files are arranged by winter season in compressed files (YYP.zip and YYPN.zip, where “YY”, “N” are defined above, and “P” is an indicator for plot files.

Image File Names: YYdddI.GIF, where “YY”, “ddd”, and “I” are defined above.

Animation file Names: YYYYN.AVI, where “YYYY” and “N”, are defined above.

Click on [ftp://ftp.glerl.noaa.gov/publications/tech\\_reports/glerl-133/appendix1/grids](ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-133/appendix1/grids) to download anomaly ice chart grid files.

Click on [ftp://ftp.glerl.noaa.gov/publications/tech\\_reports/glerl-133/appendix1/animations](ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-133/appendix1/animations) to download computer animations for each winter. There are two animations for winters 1989, 1990, 1991, 1992, 1993, 1994, and 1995 because there were separate NIC and CIS ice chart anomaly files those winters.

Click on [ftp://ftp.glerl.noaa.gov/publications/tech\\_reports/glerl-133/appendix1/images](ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-133/appendix1/images) to download images used to create the computer animations.

## APPENDIX 2. LAKE DEPTH, LAKE ID GRIDS AND SPATIAL AVERAGE ICE COVER.

Lake Depth Grid. Depth24x.new is the name of a grid of lake depth in meters. There are 510 records. Each record has a format of 516 (I3), where I = integer format. Land cells are coded with -1.

Lake ID Grid. GLmask2.txt is the name of a ASCII file that is a land mask grid with a single digit numeric code for each of the Great Lake and for some of the connecting channels. There are 510 records. Each record has a format of 516 I1. Land grid cells have a code of 0, the grid cell numeric codes for the Great Lakes are as follows: Superior = 4, Michigan = 5, Huron = 6, Erie = 7, and Ontario = 8, other numeric codes in this file can be neglected.

Spatial Average Ice Cover. The spatial- averaged ice cover for five discrete depth ranges (1-20 m, 21-50 m, 51-100 m, 101-200 m, and over 200 m for Lakes Superior, Michigan, Huron, and Ontario and 1-10 m, 11-15 m, 16-20 m, 21-30 m, and over 30 m for Lake Erie) and for the entire surface area of each Great Lake (lake-averaged) was calculated for the median, first quartile, and third quartile statistics for each of the 173 overlapping weekly periods. These data are summarized in three *tab delimited* ASCII files for each Great Lake.

Lake	File Names		
	3 <sup>rd</sup> Quartile	Median	1 <sup>st</sup> Quartile
<b>Lake Superior:</b>	SUP Q75.txt	SUP Q50.txt	SUP Q25.txt
<b>Lake Michigan:</b>	MIC Q75.txt	MIC Q50.txt	MIC Q25.txt
<b>Lake Huron:</b>	HUR Q75.txt	HUR Q50.txt	HUR Q25.txt
<b>Lake Erie:</b>	ERI Q75.txt	ERI Q50.txt	ERI Q25.txt
<b>Lake Ontario:</b>	ONT Q75.txt	ONT Q50.txt	ONT Q25.txt

### File Structure

Record 1. Title: Lake Name                      upper limit of depth range                      Entire  
 Record 2. Title: jdate    20       50       100       200       >200    Lake  
 Records 3 - 175, tab delimited list of date, Julian date, ice data for 5 depth ranges, lake average ice data.

The first 6 records of SUP Q75.txt are shown below as an example.

### Record

1	L. Superior		upper limit of depth range					Entire
2		jdate	20	50	100	200	>200	Lake
3	Dec01qr3	335	12.6	0.7	0.1	0.0	0.0	1.1
4	Dec02qr3	336	12.8	0.8	0.1	0.0	0.0	1.1
5	Dec03qr3	337	13.2	0.8	0.1	0.0	0.0	1.1
6	Dec04qr3	338	13.1	0.8	0.1	0.0	0.0	1.1

Where “qr3” following the date is an indicator for Q75, in files for Q25 “qr1” is an indicator following the date, and in files for Q50 “med” is an indicator that follows the date.

Click on [ftp://ftp.glerl.noaa.gov/publications/tech\\_reports/glerl-133/appendix2/](ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-133/appendix2/) to download the depth grid file (Depth24x.new), the Lake ID grid file (GLmask2.txt), or any of the 15 spatial average ice cover files given in the table above (SUP Q75.txt, SUP Q50.txt, ..ONT Q75.txt, ONT Q50.txt, ONT Q25.txt).